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Mehzad Javeed, Harold H. Edighoffer, and Paul E. McGowan

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Mehzad Javeed
Lockheed Engineering and Sciences Company
Hampton, VA

Harold H. Edighoffer
Analytical Services and Materials Inc.
Hampton, VA

Paul E. McGowan
NASA Langley Research Center
Hampton, VA

Abstract

Verification of analytical models through correlation with ground test results of a complex space truss structure is demonstrated. A multi-component, dynamically scaled space station model configuration is the focus structure for this work. Previously established test/analysis correlation procedures are used to develop improved component analytical models. Integrated system analytical models, consisting of updated component analytical models, are compared with modal test results to establish the accuracy of system-level dynamic predictions. Design sensitivity model updating methods are shown to be effective for providing improved component analytical models. Also, the effects of component model accuracy and interface modeling fidelity on the accuracy of integrated model predictions is examined.

Introduction

Correlation of ground test results with analytical predictions is a key aspect in the verification of analytical models of aerospace structures. In particular, it is common practice in many aerospace applications to require a verified finite element model (FEM) in order to produce response or load predictions. Since many proposed space structural systems are composed of numerous interconnected components or subsystems, the verification process is dependent on the accuracy of the individual component models which are used to form the integrated system-level analytical model.

Accuracy of the component models relies on the test/analysis correlation and model updating procedures. There are several approaches for obtaining correlated analytical models which have been previously applied to spacecraft systems [1-3]. Typically, this involves the combination of engineering judgment with one or more mathematical procedures to develop updated analytical models of various components.

Once the component models have been updated, one of two methods must be selected for developing the integrated system model. One method involves developing a synthesized model from component modal information and is often referred to as Component Modal Synthesis [4,5].

The second method provides a large, fully-mated FEM consisting of component models combined directly together. In either case, the fidelity and reliability of component model interfaces are key to the modeling and test verification of a subsystem consisting of several connected components. Ultimately, final verification of the integrated model requires test results of the full system.

This paper presents the results of a research effort aimed at developing a verified analytical model of an integrated complex space truss structure through correlation with ground test results. Using a dynamically scaled space station structural model, the correlation of component analytical models and the subsequent integration into system-level analytical models is demonstrated. Accuracy of the final integrated models is evaluated through correlation of analyses with system-level ground test models.

Background

As a focus for this work, consider a previously proposed design for Space Station Freedom (Figure 1). This structure consists of a number of power, payload, and habitat systems interconnected through an erectable, multi-member truss structure. Due to the large size and weight of this class of structure, and the effects of gravity, system-level ground vibration tests are not feasible. Thus, verification of the integrated system model must ultimately be performed using updated component models which are then synthesized to provide system-level response predictions.

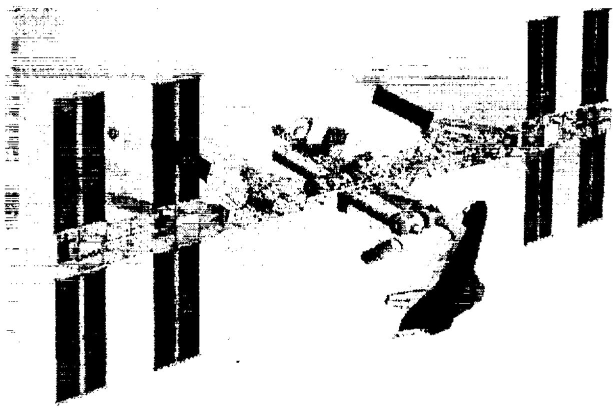

Figure 1. Early Space Station Freedom Concept.

To address aspects of the verification issue, a technology program investigating the use of scale models for predicting the dynamics of large space truss structures is underway at the NASA Langley Research Center [6]. A dynamically similar scale model of the structure shown in Figure 1 has been developed [7]. This is a 1/5:1/10 hybrid-scale model (1/5-scale dynamics, and 1/10-scale geometry) of the previous space station design. All major structural components have been included in the design of the model, thus the assembled model has many of the dynamic characteristics representative of the full-scale system. The scale model configuration was assembled to resemble a Mission Build 2 (MB-2) configuration of the then proposed full-scale space station. The hybrid model designation of the MB-2 configuration is referred to as Hybrid Mission Build 2 (HMB-2).

One aspect of this study was the interaction of the scaled solar array and radiator components with the global truss system. This was of interest since the vibration frequencies of these components are approximately the same as the fundamental frequencies of the integrated system. To address this interaction, two versions of these components were constructed, namely flexible and rigid simulators. This allowed the effects of the solar array and radiator dynamics to be systematically separated from the system. The models assembled from rigid and flexible versions of the simulators are referred to as HMB-2R and HMB-2F, respectively (see Figures 2 and 3).

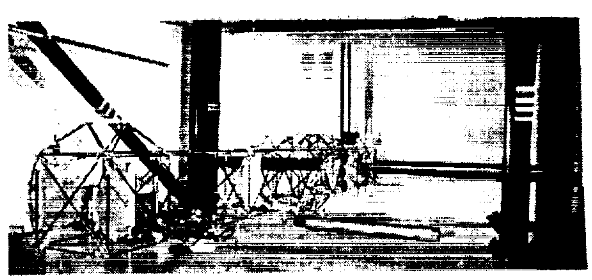

Figure 2. Hybrid-Scale HMB-2R Model Configuration.

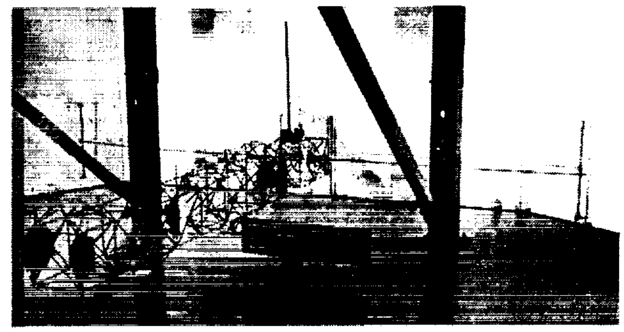

Figure 3. Hybrid-Scale HMB-2F Model Configuration.

For this study, the major structural components were individually tested and those results were used to produce updated analytical models. Whenever possible, each of the components was tested and analyzed in the configuration that best represented the component behavior as part of the integrated system. However, in some cases the boundary conditions were selected for testing convenience or practicality. MSC/NASTRAN FEM's were used for the component and integrated analyses [8]. In addition, design sensitivity analysis was used along with engineering judgment to produce the updated models [9-11]. In some cases, the initial FEM's were highly inaccurate since they were developed prior to fabrication of the hardware. In other cases, the pre-test component FEM's were very accurate since extensive testing of the individual component's structural members was completed and that information was included in the pre-test FEM.

As mentioned above, the MSC/NASTRAN program was used to analyze the component and system-level FEM's in this study. The Structural Dynamics Research Corporation (SDRC) DATM program was used on a GenRad 2515 for test-data acquisition [12]. The Test Data Analysis module of the I-DEAS package of SDRC was used for test-data analysis [13].

Both scale model configurations, HMB-2R and HMB-2F, were separately considered as integrated systems. The system-level analytical models were constructed by directly connecting the updated component models to form one fully integrated analytical model for each configuration. Vibration tests of each integrated system provided the final results for verification of the integrated model accuracy.

Test Articles

The HMB-2R and HMB-2F models were each divided into 22 components (Figure 4). As noted above, there are rigid and flexible versions of the solar arrays as well as the Electrical Power System (EPS) and Thermal Control System (TCS) radiators. With the exception of these components, the remaining 18 components are common between the HMB-2R and HMB-2F models.

Table 1 summarizes the components of each of the HMB-2 models. In some cases, when more than one of a particular component existed, only one of that type was tested. In those cases, the remaining components of that type were assumed to have identical structural properties. Thus, a total of 15 components were tested from the 26 listed in Table 1.

Component Test/Analysis Correlation

The test/analysis correlation approach adopted in this work is presented schematically in Figure 5. This approach consists of updating the initial FEM of each component based on the results of the test-data analyses (test models). The correlation analysis consists of two steps and results in an updated FEM for each component. The first step consists of evaluating the component model to assure proper representation of the important features of each component. Engineering judgment was the primary driver for these model changes. Once the component models were judged to have appropriate detail and complexity, the models were updated in the second step of the correlation analysis through design sensitivity analyses. The tool utilized in this step was the MSC/NASTRAN design sensitivity approach [9]. The SDRC-developed CORDS program was used to post process the results of the sensitivity analyses [14].

The results of the correlation analyses are presented in terms of frequency comparison and the cross-orthogonality of the test and FEM modes. The cross-orthogonality (XO) is defined as :

$$XO = \left[\bar{\Phi}\right]^T [M][\Phi] \qquad (1)$$

where $\left[\bar{\Phi}\right]$ and $[\Phi]$ represent the test and FEM modes, respectively, and $[M]$ represents the reduced component mass matrix.

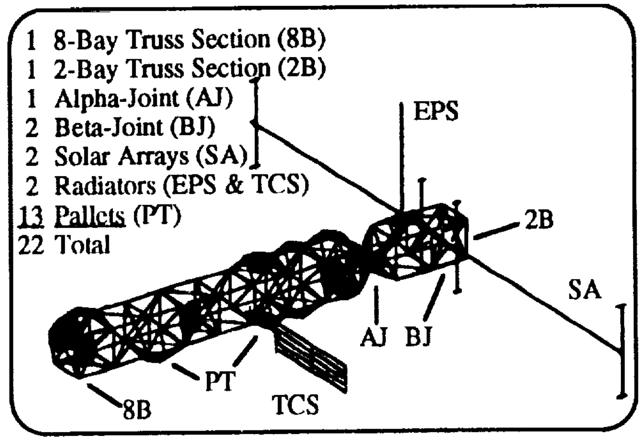

Figure 4. Focus Structure Mission Build 2 (MB-2) with Flexible EPS, TCS and Solar Arrays.

Table 1. Summary of HMB-2 Model Components.

Component Name	Quantity	Number Tested
8-Bay Truss	1	1
2-Bay Truss	1	--
Alpha-Joint	1	1
Beta-Joint	2	2
4-Sided Pallet	5	1
6-Sided Pallet	6	1
8-Sided Pallet	2	1
EPS Radiator (Rigid)	1	1
EPS Radiator (Flexible)	1	1
TCS Radiator (Rigid)	1	1
TCS Radiator (Flexible)	1	1
Solar Array (Rigid)	2	2
Solar Array (Flexible)	2	2
Total	26	15

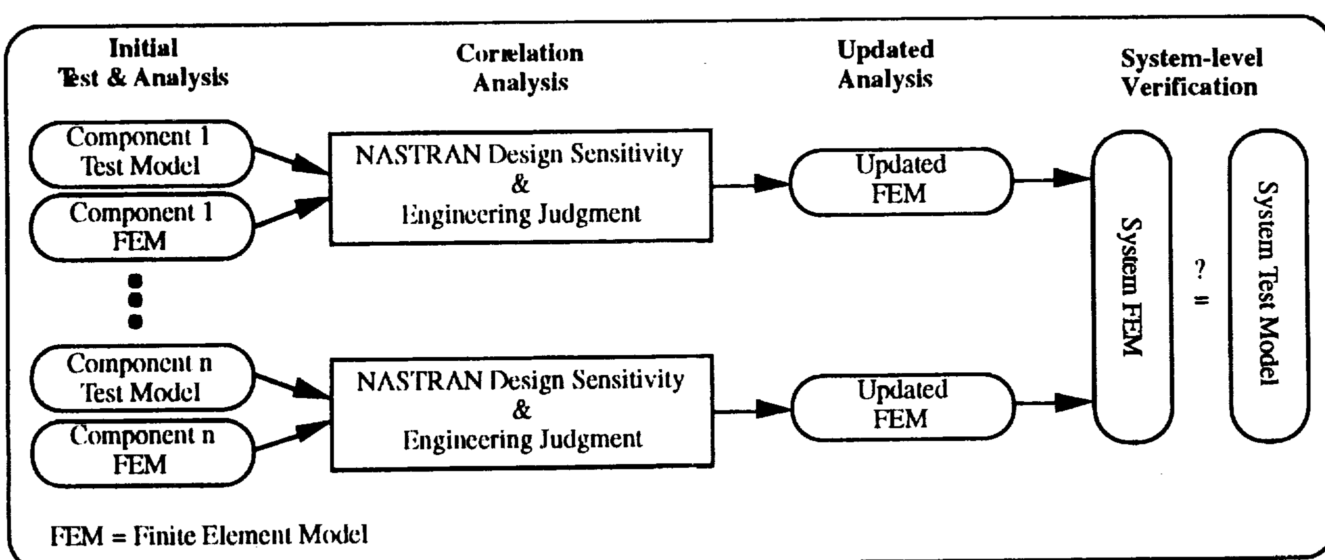

Figure 5. Test/Analysis Verification Approach.

A cross-orthogonality of one (or 100%) indicates that the mass-weighted deflection patterns of two mode shapes are identical to within a scale factor. When the cross-orthogonality is zero, two modes are completely orthogonal. The Guyan reduction was used to reduce the FEM mass matrices to match the test degrees-of-freedom for cross-orthogonality calculations [15-17].

The 8-bay truss section, which is the primary structure of both the HMB-2R and HMB-2F models, was tested in a cantilevered configuration. Results of the correlation analyses are summarized in Table 2. The test/analysis correlation focused on the first five structural modes of the component. For modes greater than five, the individual truss strut modes dominate the structural behavior. The frequency and cross-orthogonality comparisons of the pre-test and updated FEM's with the test results indicate moderate improvement in structural characteristics of the 8-bay truss. Due to *a priori* knowledge of the truss strut axial stiffness properties, from individual strut static tests, the pre-test FEM was in good agreement with test data. Thus, only moderate improvements were achievable through the correlation analyses. The primary properties that were updated in the correlation analyses were the strut bending characteristics and the mass distribution. Due to similarity of the 2-bay and 8-bay truss sections, it was assumed that the structural properties of both components were identical. Therefore, no test and correlation analyses were performed for the 2-bay truss component.

The Alpha-Joint was tested in both free-free and cantilevered configurations. The results of the correlation analyses of the cantilevered configuration of the Alpha-Joint component are presented in Table 3. Due to complexity of this component and a lack of knowledge about the local behavior of the strut members, the pre-test FEM did not agree closely with test data. Correlation analyses indicated changes in the thickness of two plates, which represent the two halves of the Alpha-Joint, and the area and area moment of inertia of the Alpha-Joint connecting struts. These modifications provided an updated model which considerably improved the test/analysis correlation for this component.

The Beta-Joint component was tested in a fixed-free configuration; fixed at the interfaces to the truss and free at the interface to the solar array. The pre-test FEM of the Beta-Joint showed the largest disagreement with the component test data, as indicated in Table 4. This was primarily due to coarse modeling of the main canister of the joint using rigid elements. The FEM was modified to include more internal detail as well as test verified strut element properties. The updated FEM shows much better agreement with test data as shown in Table 4.

Similarly, results of the correlation analyses for the pallets (4-, 6- and 8-sided); and both rigid and flexible versions of the EPS, TCS, and solar arrays are presented in Tables 5-13. Similar procedures to those described above were used for updating these component models. The data presented in these tables indicate improvements in component models as the result of the correlation analyses.

The results of the correlation analyses are summarized in Tables 14 and 15. The top row of Table 14 shows that the average component frequency error among the FEM and test models was reduced from 28.0% to 3.0% as a result of updating the HMB-2R component models. Also, the average cross-orthogonality was increased from 90 to 93. Similarly, the top row of Table 15 shows that the average component frequency error among the FEM and test models was reduced from 26.2% to 3.1%, and the average cross-orthogonality was increased from 90 to 93 as a result of the verification of HMB-2F component models.

System Test/Analysis Correlation

The laboratory models of the HMB-2R and HMB-2F models were suspended from a fixed gantry structure with a 40 foot height. Each structure underwent vibration tests while suspended from cables to simulate a "free-free" configuration. The response to multi-input burst random force excitation was measured with approximately 100 acceleration transducers to determine experimentally the modal parameters of the structures.

The system FEM's of the HMB-2R and HMB-2F configurations were constructed by integrating the individual component finite element models. These models included the cable suspension effects to simulate the laboratory conditions. The effect of gravity on the FEM's stiffness was also included in the analyses since the behavior of some of the components and the suspension cables are altered by this effect.

HMB-2R Configuration

The integrated HMB-2R system FEM was analyzed to determine the system modal properties. There were 13 structural elastic modes in the frequency range of 0-25 Hz. Based on the dynamic scale factor of 5 for the hybrid-scale model, this frequency range would correspond to a full-scale frequency range of 0-5 Hz.

The system-level model constructed from initial or pre-test component models was compared with the test model that was derived from the analysis of the laboratory data. This comparison showed major disagreements between the FEM and the test models. This discrepancy is indicated by an average frequency error of 17.0% and an average cross-orthogonality of 84 among the FEM and test model modes. Note that the pre-test system FEM did not predict the sixth structural mode of the system.

The system-level model constructed from the updated or test verified component models showed better agreement with the test model. This is indicated by an average frequency error of 4.2% and an average cross-orthogonality of 93 among the FEM and test model modes.

The HMB-2R system model was examined for further improvements. Since the individual component FEM's were updated based on test-data analysis results, the modeling of interfaces between the components was examined next. Linear springs elements were used to represent the compliance of the bolted joints between the Beta-Joint and solar arrays, and between the EPS, and TCS radiators and their supporting pallets. The modeling of the interface joints compliance further reduced the average frequency error and increased the average cross-orthogonality among the FEM and test model modes to 2.3% and 97, respectively. System modes 6, 7, and 11 showed noticeable improvement as the result of modeling the interface joints. These mode shapes primarily involve deflection of the TCS radiator and solar arrays.

The mass and stiffness matrices of the reduced (Guyan) system correctly predicted all 13 system modes. This implies that the number and location of the instrumented points were appropriate to characterize the system.

The frequency comparison and cross-orthogonality among the test and each of the three system-level FEM's are shown in Figures 6 and 7. The comparison of results are also presented in the test/analysis correlation summary found in the second row of Table 14.

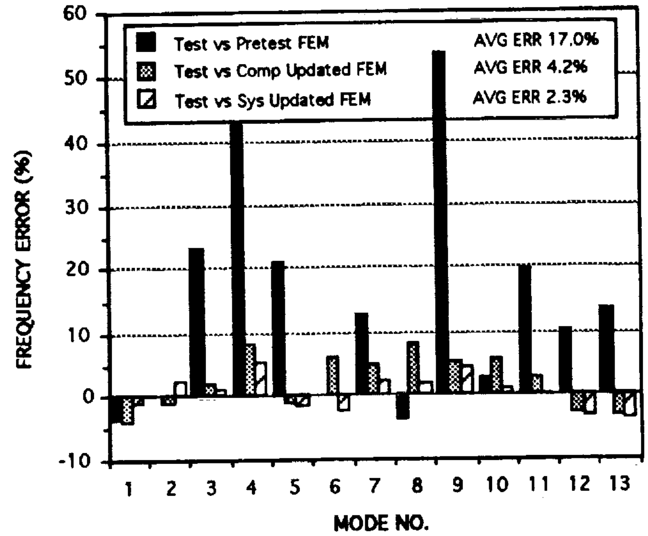

Figure 6. HMB-2R Test/Analysis Frequency Comparison.

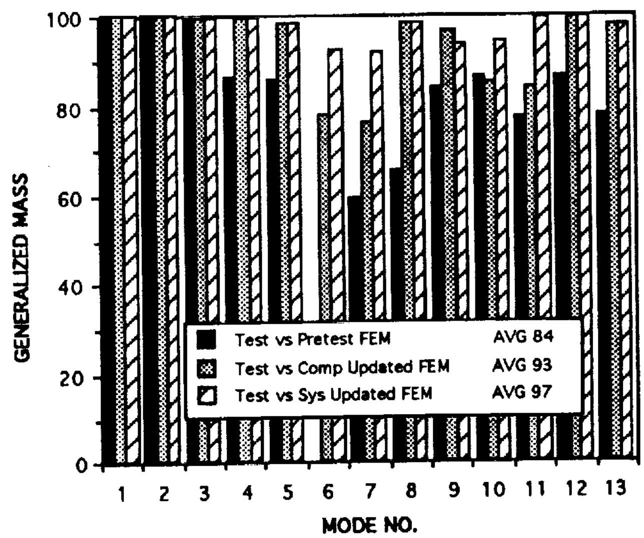

Figure 7. HMB-2R Test/Analysis Cross-Orthogonality Comparison.

HMB-2F Configuration

The integrated HMB-2F system has a much higher modal density than the HMB-2R system. There are 44 structural elastic modes in the frequency range of 0-25 Hz. Based on the dynamic scale factor of 5 for the hybrid-scale model, these results correspond to a full scale frequency range of 0-5 Hz. In fact, the number of full-scale system modes is expected to increase significantly as more complex models of the EPS and TCS radiators and the solar arrays are fabricated and included in the system.

Correlation results of the HMB-2F system model are presented in Figures 8 and 9. The correlation analysis of the initial HMB-2F system model that was constructed from pre-test component models shows frequency error of 7.2% and cross-orthogonality of 84 among the FEM and test modes. In addition, the pre-test FEM model did not predict 5 system modes, namely modes 13, 20, 30, 35, and 37. The deflection pattern of these modes primarily involved higher bending modes of the solar arrays and radiators.

The comparison of the HMB-2F system model, constructed from updated component FEM's, and the test results indicate an average frequency error of 4.3% and a cross-orthogonality of 84 among FEM and test modes. Due to more accurate representations of the component models, this improved system model predicted the five modes that were missed in the pre-test model of HMB-2F.

System modes 4 and 5 indicate poor cross-orthogonality while mode 4 also indicates poor frequency comparison between the FEM and test model. These modes involve the in-phase and out-of-phase torsion of the solar arrays. These results indicate that there are some differences between the torsional characteristics of the two solar array components.

This suggests that each solar array must be tested and the corresponding correlated model for each solar array should be included in the system model. This finding was contrary to initial assumptions that all similar structures had the same properties.

The HMB-2F system model was modified to include linear spring elements to represent the compliance of the interface bolted joints, as in the case of HMB-2R model. In addition, individual models of each of the solar arrays were created to represent their unique characteristics. The modifications resulted in an average frequency error of 4.0% and no change in the cross-orthogonality (84) among the FEM and test modes of the system. The overall frequency comparison and the cross-orthogonality values between the test and FEM indicate very good correlation.

There are eleven modes that indicate less than desirable correlation between FEM and test model, namely modes 9, 28, 30, 32, 33, 35 through 39, and 41. Mode nine involves the rolling of the structure as a rigid body with out-of-phase bending of solar arrays. Closer examination of this mode has not lead to any explanation for this discrepancy. The remaining modes all involve higher panel bending modes of the TCS radiator. Recall from Table 11 that this result follows from the less than desirable component correlation results for some TCS modes. The disagreements between the FEM and test data at the component level is due to lack of modeling of each of the panels with different properties to match their individual characteristics. The TCS component is constructed of five long, thin panels that are connected to each other by a thin strap at the midpoint and end locations of the panels. Further examination of the TCS revealed that the individual panels were visibly warped. No attempt was made to model this behavior.

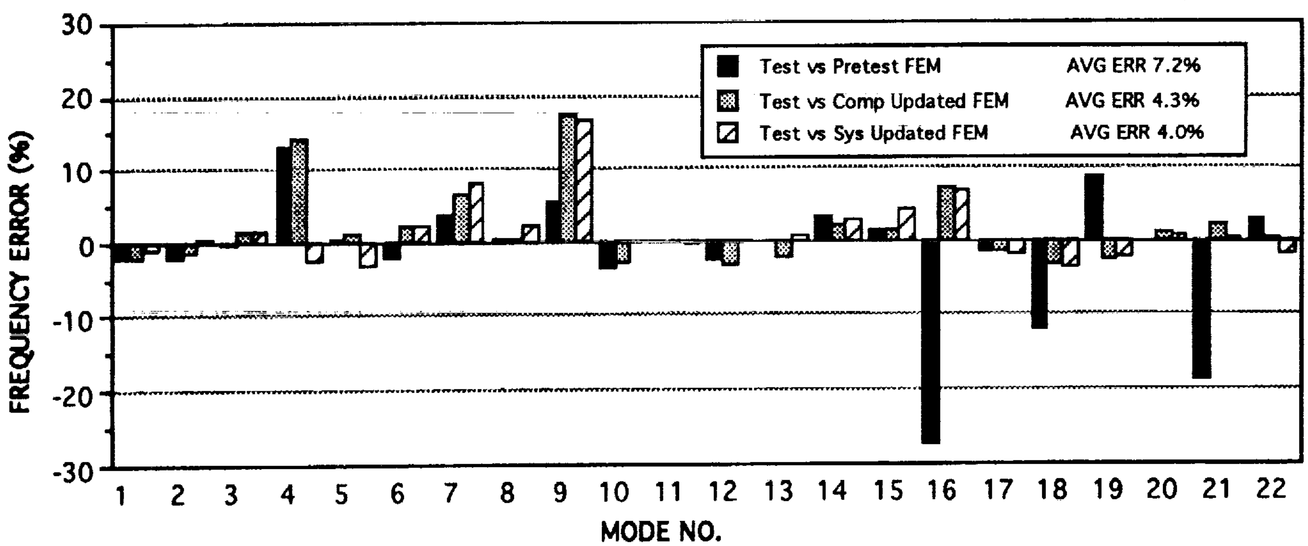

Figure 8a. HMB-2F Test/Analysis Frequency Comparison, Modes 1-22.

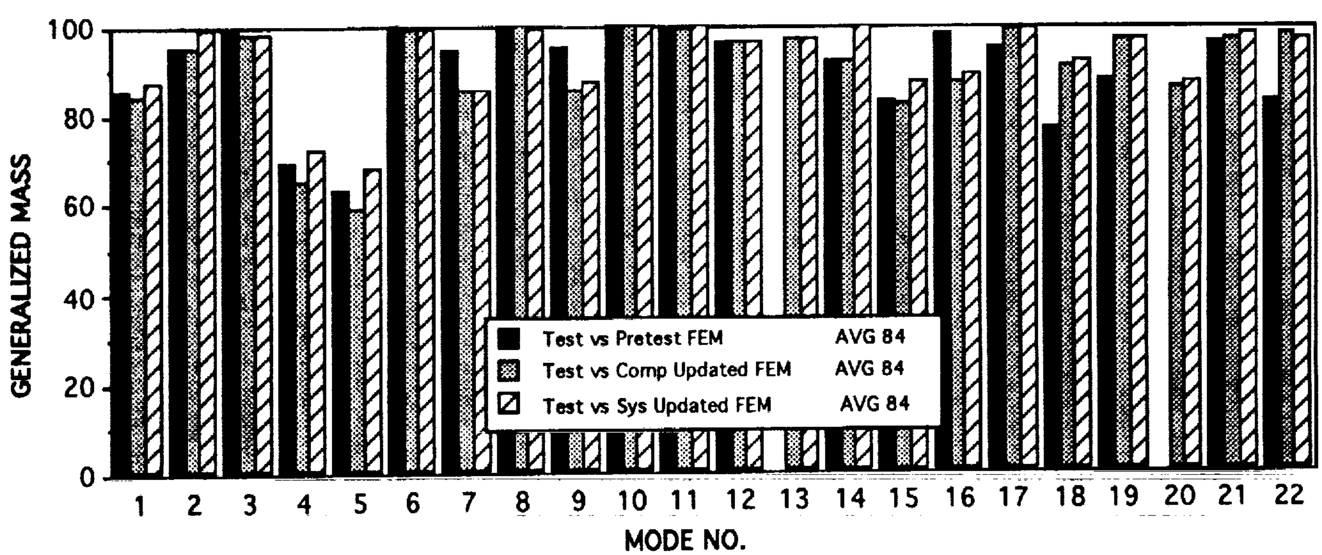

Figure 8b. HMB-2F Test/Analysis Cross-Orthogonality Comparison, Modes 1-22.

Inclusion of correlated models for each of the solar arrays reduced the frequency error associated with mode 4 and made minor improvements in the cross-orthogonality of modes 4 and 5. Closer examination of these modes indicated that the deflection pattern of the FEM modes are purely torsional while the deflection pattern of the experimental modes involves torsion and some bending. Further refinement of the model would be required to capture this effect. The results of the test/analysis correlation of HMB-2F model are also summarized in the second row of Table 15.

The mass and stiffness matrices of the reduced (Guyan) system predicted 32 of 44 system modes. Modes 26, 30, 33 through 39, 41, 42, and 44 were not predicted by the reduced system. This is due to the fact that the system FEM used in the pre-test analysis to determine the number and location of the instrumentation points did not include test verified models of several components. These components included the EPS and TCS radiators, solar arrays, Alpha-Joint, and various pallets. Therefore, the number and location of the instrumented points were not sufficient for the complexity of this system. The inability of the reduced system model to predict the system modes mentioned above explains the low cross-orthogonality values associated with these modes. Also, there was no attempt in this work to investigate possible improvements in reduced model characteristics that might result from using alternate reduction methods (e.g. Improved Reduced System) [17].

Concluding Remarks

Correlation of ground vibration test results with analytical predictions of a scaled space station model has been presented. Both component-level and system-level tests and analyses were performed. System-level analysis verification was demonstrated by directly combining updated component-level models. A high degree of correlation between analytical and system-level tests was achieved.

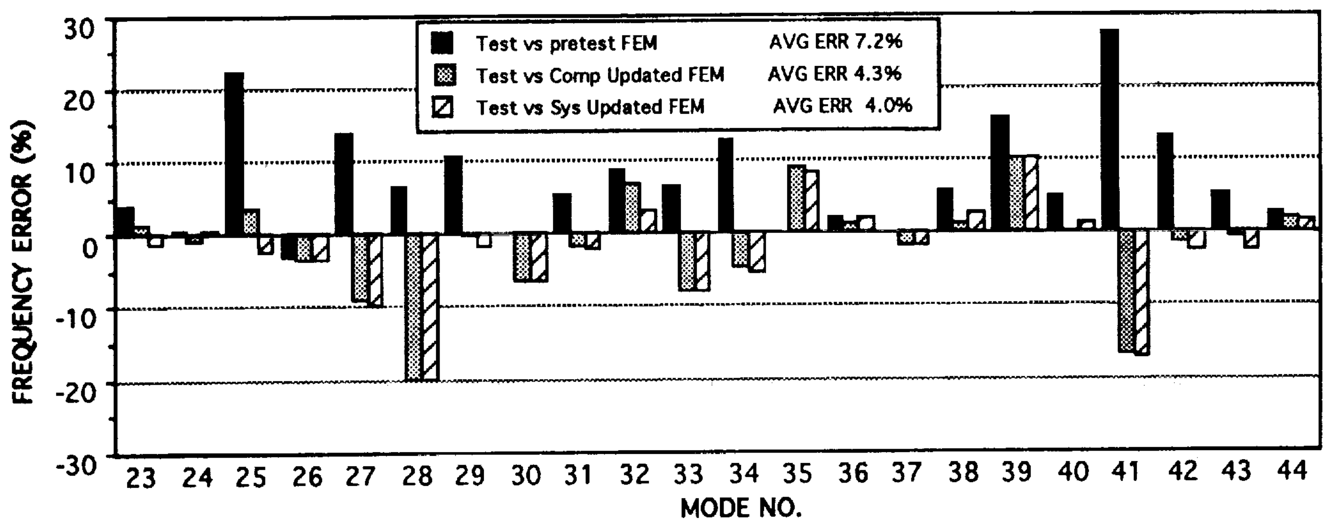

Figure 9a. HMB-2F Test/Analysis Frequency Comparison, Modes 23-44.

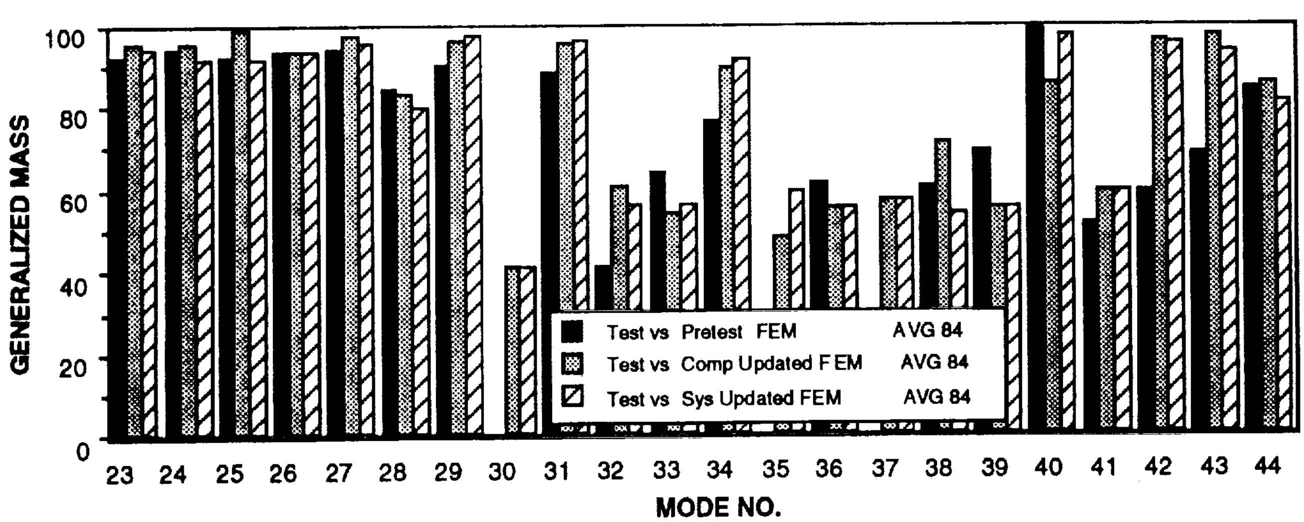

Figure 9b. HMB-2F Test/Analysis Cross-Orthogonality Comparison, Modes 23-44.

Design sensitivity procedures have been shown effective for updating component-level models. Significant improvement in pre-test component models was demonstrated through correlation with component ground test results. Also, the effect of component model accuracy on system-level integrated model accuracy was shown. This result suggests that the use of unverified pre-test component models can lead to erroneous system-level analytical predictions.

The results indicate that the approach adopted in this study is acceptable for verification of complex space truss structures. The availability of system-level test results provided a means to evaluate the accuracy of system-level models which in turn are dependent on modeling of interface connections of components. In particular, it was shown that detailed modeling of component interface compliance, as opposed to assuming rigid connections, further improves the overall system correlation.

Acknowledgments

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References

1. Roy, N. A.; et al: *A Survey of Finite Element Model Updating Methods*. Proceedings of the International Symposium on Environmental Testing for Space Programmes - Test Facilities & Methods, held at ESTEC, Noordwjik, The Netherlands, June 1990, pp. 333-340.

2. McGowan, P. E.; Angelucci, A. F.; and Javeed, M.: *Dynamic Test/Analysis Correlation Using Reduced Analytical Models*. NASA TM-107671, September 1992.

3. Brillhart, R. D.; Freed, A. M.; and Hunt, D. L.: *Modal Test and Correlation of the Commercial Titan Dual Payload Carrier*. Proceedings of the Eighth International Modal Analysis Conference, Kissimmee, Florida, February 1990, pp. 912-918.

4. Craig, Roy R.: Structural Dynamics: an Introduction to Computer Methods. John Wiley & Sons, New York, 1981, pp. 467-493.

5. Craig, Roy R.; and Bampton, Mervyn C. C.: *Coupling of Substructures for Dynamic Analysis*. AIAA Journal, Vol. 6, No. 7, July, 1968.

6. McGowan, P. E.; Javeed, M.; and Edighoffer, H. H.: *Status of DSMT Research*. NASA TM-102764, January 1991.

7. Gronet, Marc J.; Crawley, Edward, F.; and Allen, Bradley R.: *Design, Analysis, and Testing of a Hybrid Scale Structural Dynamic Model of a Space Station*. AIAA Paper No. 89-1340-CP, Presented at the 30th AIAA SDM Conference, Mobile, Alabama, April 1989.

8. MSC/NASTRAN User's Manual, the MacNeal-Schwendler Corporation, Los Angles, CA.

9. MSC/NASTRAN Application Manual, Volume 1, Section 3.4, the MacNeal-Schwendler Corporation, Los Angles, CA.

10. Flanigan, C. C.: *Test/Analysis Correlation of the STS Centaur Using Design Sensitivity And Optimization Methods*. Proceedings of the 5th International Modal Analysis Conference, London, England, April, 1987.

11. Flanigan, C. C.: *Test/Analysis Correlation Using Design Sensitivity and Optimization*. Society of Automotive Engineers, Aerospace Technology Conference and Exposition, Long Beach California, October, 1987.

12. I-DEAS Modal Plus User's Guide, Version 9.0, Structural Dynamics Research Corporation, Cincinnati, Ohio, 1985.

13. I-DEAS Test Data Analysis User's Guide, level VI, Structural Dynamics Research Corporation, Cincinnati, Ohio, 1990.

14. CORDS Users Manual, Version 1.0, Structural Dynamics Research Corporation, San Diego, California, 1988.

15. Guyan, R. J.: *Reduction of Stiffness and Mass Matrices*. AIAA Journal, Vol. 3, February 1965.

16. Freed, A. M.; and Flanigan, C. C.: *A Comparison of Test-Analysis Model Reduction Methods*, Sound and Vibration, Vol. 25, No. 3, March 1991, pp. 30-35.

17. McGowan, P. E.: *Dynamic Test/Analysis Correlation Using Reduced Analytical Models*, Master of Science Thesis, Department of Mechanical Engineering and Mechanics, Old Dominion University, Norfolk, Virginia, June 1991.

Table 2. 8-Bay Truss Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	14.0	13.3	-5.0	96.0	14.3	2.1	95.6
2	14.4	13.7	-4.9	92.1	14.8	2.5	91.7
3	48.4	50.5	4.3	98.2	50.8	5.0	99.5
4	64.3	62.5	-2.7	97.5	65.8	2.3	97.9
5	67.4	66.2	-1.9	97.8	69.7	3.4	98.0
Average Value			3.8	96		3.1	97

Table 3. Alpha-Joint Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	33.9	52.5	54.9	96.0	33.6	-0.9	99.0
2	34.2	52.5	53.5	94.0	33.6	-1.8	97.0
3	58.5	58.9	0.7	99.0	58.0	-0.9	99.0
4	66.0	110.5	67.4	97.0	66.7	1.1	100.0
5	114.3	132.5	16.0	90.0	116.5	2.0	99.0
6	116.0	132.5	14.2	89.0	116.5	0.4	94.0
7	123.7	111.1	-10.2	86.0	128.3	3.7	86.0
8	128.3	130.6	1.8	99.0	126.2	-1.6	100.0
9	133.6	110.8	-17.1	89.0	129.0	-3.4	89.0
Average Value			20.1	93		1.8	96

Table 4. Beta-Joint Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	69.7	258.9	271.7	66.0	70.3	0.9	98.4
2	235.4	158.5	-32.7	100.0	251.4	6.8	99.7
Average Value			152.2	83		3.9	99

Table 5. 4-Sided Pallet Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	270.8	289.6	6.9	71.0	278.4	2.8	71.0
2	273.4	291.9	6.8	65.0	274.5	0.4	68.0
3	273.5	290.9	6.4	97.0	277.6	1.5	96.0
Average Value			6.7	78		1.6	78

Table 6. 6-Sided Pallet Component Test/Analysis Correlation Summary.

Mode Number	Test Freq. (HZ)	Pre-test FEM Freq. (HZ)	Pre-test % Error	Pre-test Cross-Orthogonality	Updated FEM Freq. (HZ)	Updated % Error	Updated Cross-Orthogonality
1	149.9	177.2	18.2	86.2	150.8	0.6	99.0
2	168.0	166.2	-1.1	87.6	168.6	0.4	99.5
3	222.4	308.0	38.5	86.6	225.7	1.5	91.1
Average	Value		19.3	89		0.8	97

Table 7. 8-Sided Pallet Component Test/Analysis Correlation Summary.

Mode Number	Test Freq. (HZ)	Pre-test FEM Freq. (HZ)	Pre-test % Error	Pre-test Cross-Orthogonality	Updated FEM Freq. (HZ)	Updated % Error	Updated Cross-Orthogonality
1	140.0	154.5	10.4	90.0	138.9	-0.8	90.0
2	140.0	154.5	10.4	84.0	138.9	-0.8	85.0
3	193.6	208.8	7.9	100.0	202.0	4.3	99.0
4	260.0	299.0	15.0	92.0	277.6	6.8	91.0
5	284.0	320.0	12.7	89.0	285.7	0.6	89.0
Average	Value		11.3	91		2.7	91

Table 8. EPS Radiator (Rigid) Component Test/Analysis Correlation Summary.

Mode Number	Test Freq. (HZ)	Pre-test FEM Freq. (HZ)	Pre-test % Error	Pre-test Cross-Orthogonality	Updated FEM Freq. (HZ)	Updated % Error	Updated Cross-Orthogonality
1	43.5	46.4	6.6	99.4	44.2	1.5	99.4
2	43.9	46.4	5.6	99.3	44.2	0.6	99.2
3	324.0	363.3	12.1	69.5	341.2	5.3	91.6
4	327.2	363.3	11.0	88.8	341.2	4.3	94.8
Average	Value		8.8	89		2.9	96

Table 9. EPS Radiator (Flexible) Component Test/Analysis Correlation Summary.

Mode Number	Test Freq. (HZ)	Pre-test FEM Freq. (HZ)	Pre-test % Error	Pre-test Cross-Orthogonality	Updated FEM Freq. (HZ)	Updated % Error	Updated Cross-Orthogonality
1	1.2	1.1	-5.7	99.7	1.2	-1.2	99.7
2	8.1	7.7	-4.9	99.9	8.0	-1.0	99.9
3	22.8	21.7	-4.6	100.0	22.6	-0.9	100.0
4	24.4	27.3	11.8	100.0	24.8	1.8	100.0
Average	Value		6.8	100		1.2	100

Table 10. TCS Radiator (Rigid) Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	23.1	26.1	12.9	99.5	23.1	-0.1	99.6
2	23.4	27.7	18.7	99.6	23.4	0.0	99.8
3	273.1	311.2	14.0	91.9	269.5	-1.3	91.8
4	289.4	330.4	14.2	93.9	296.3	2.4	92.4
Average Value			14.9	96		1.0	96

Table 11. TCS Radiator (Flexible) Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	1.3	1.2	-4.5	100.0	1.3	0.0	100.0
2	7.4	7.6	3.7	84.0	7.4	0.1	97.0
3	7.7	7.8	1.0	84.0	8.1	3.9	97.0
4	13.8	13.0	-5.9	89.0	12.4	-10.1	91.0
5	15.5	15.3	-1.2	98.0	15.4	0.0	98.0
6	17.0	16.7	-2.0	68.0	16.0	-6.1	69.0
7	17.7	14.1	-20.2	88.0	13.8	-21.7	89.0
8	19.8	18.8	-5.1	45.0	18.1	-8.5	46.0
9	22.1	20.1	-9.0	68.0	19.6	-11.6	68.0
10	23.4	21.7	-7.1	90.0	22.3	-4.6	90.0
11	26.3	28.9	10.0	82.0	28.6	8.9	84.0
Average Value			6.3	82		6.9	85

Table 12. Solar Array (Rigid) Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	18.9	21.4	13.5	99.7	19.8	5.1	99.0
2	19.0	21.4	12.7	99.1	19.8	4.3	99.8
3	147.0	155.8	6.0	90.4	165.8	12.8	64.3
4	148.6	155.8	4.9	79.8	165.8	11.6	84.5
Average Value			9.2	92		8.4	87

Table 13. Solar Array (Flexible) Component Test/Analysis Correlation Summary.

		Pre-test			Updated		
Mode Number	Test Freq. (HZ)	FEM Freq. (HZ)	% Error	Cross-Orthogonality	FEM Freq. (HZ)	% Error	Cross-Orthogonality
1	0.4	0.4	-2.9	94.0	0.4	-2.9	94.0
2	0.4	0.4	-3.8	97.0	0.4	-3.8	97.0
3	1.3	1.2	-2.3	100.0	1.2	-2.4	100.0
4	3.5	3.5	-2.1	100.0	3.4	-2.2	100.0
5	5.7	5.7	1.4	99.0	5.7	1.4	99.0
6	9.5	9.5	0.4	98.0	9.5	0.2	98.0
7	18.6	18.8	1.3	87.0	18.8	1.2	87.0
8	19.9	19.9	0.3	100.0	19.3	-3.0	100.0
9	20.7	22.2	7.2	92.0	21.5	4.0	97.0
10	23.1	24.6	6.5	96.0	23.2	0.5	96.0
11	23.8	24.2	1.8	92.0	23.8	0.3	95.0
12	26.8	29.9	11.5	99.0	27.8	3.6	99.0
13	27.5	29.6	7.7	100.0	27.5	0.2	100.0
Average Value			3.8	97		2.0	97

Table 14. HMB-2R Component and System Test/Analysis Correlation Summary.

	Pre-test FEM	**Updated Component FEM**	**Updated System FEM**
Component Models	Average Frequency Error 28.0% Average Cross-Orthogonality 90	Average Frequency Error 3.0% Average Cross-Orthogonality 93	
System Models	Average Frequency Error 17.0% Average Cross-Orthogonality 84	Average Frequency Error 4.2% Average Cross-Orthogonality 93	Average Frequency Error 2.3% Average Cross-Orthogonality 97

Table 15. HMB-2F Component and System Test/Analysis Correlation Summary.

	Pre-test FEM	**Updated Component FEM**	**Updated System FEM**
Component Models	Average Frequency Error 26.2% Average Cross-Orthogonality 90	Average Frequency Error 3.1% Average Cross-Orthogonality 93	
System Models	Average Frequency Error 7.2% Average Cross-Orthogonality 84	Average Frequency Error 4.3% Average Cross-Orthogonality 84	Average Frequency Error 4.0% Average Cross-Orthogonality 84

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Mehzad Javeed*, Harold H. Edighoffer**, Paul E. McGowan

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13. ABSTRACT *(Maximum 200 words)*

Verification of analytical models through correlation with ground test results of a complex space truss structure is demonstrated. A multi-component, dynamically scaled space station model configuration is the focus structure for this work. Previously established test/analysis correlation procedures are used to develop improved component analytical models. Integrated system analytical models, consisting of updated component analytical models, are compared with modal test results to establish the accuracy of system-level dynamic predictions. Design sensitivity model updating methods are shown to be effective for providing improved component analytical models. Also, the effects of component model accuracy and interface modeling fidelity on the accuracy of integrated model predictions is examined.

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